METHOD AND APPARATUS FOR CHARGING BATTERIES IN A SYSTEM OF BATTERIES

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to battery chargers and more particularly to methods and apparatus for charging batteries in a system of batteries.

2. Description of Related Art

Multi-battery and multi-battery-bank battery systems are finding increased usage. Usage of such systems often requires charging of batteries or banks of batteries and many ways of charging have been developed. One way is to employ a single charger with a plurality of diode-isolated output stages. Another way is to employ a plurality of individual chargers all enclosed within a single enclosure. Another way is to employ a single common primary (high voltage) side architecture with either a single or multiple transformers and a plurality of secondary side isolated or non-isolated rectifier stages. Another way is to provide a single main charger module with a plurality of secondary side post regulator circuits for auxiliary battery banks for individual bank control. Another way of charging multiple batteries or battery banks is to use a single full power charger with time-domain multiplexed output stage connectable to a plurality of batteries or battery banks.

Traditional marine style multi-bank battery chargers employ the diode-isolated method described above. A diode-isolated system typically involves the use of two or more diodes connected together to prevent current flowing from one battery to another while permitting current to flow through both or all diodes at the same time allowing all batteries or battery banks to be charged at the same time. In such a system, current from the battery charger is split or shared approximately equally between batteries or battery banks when all the batteries or battery banks being charged have approximately the same state of charge. If any one battery has a lower state of charge than the other

batteries or battery banks in the system, that battery or battery bank receives most of the charging current until its state of charge is approximately equal to the next lowest charged battery and then two batteries draw current from the charger and so on. This process continues until all batteries or battery banks are charged but it places an increasing load on the charger because charging is done on all of the batteries simultaneously.

Unfortunately, diode-isolated systems are not readily adaptable to permit charging to be specifically controlled for any particular battery. This limits the ability of the batteries or battery banks to be efficiently charged and often requires that the same type of battery be used at every battery or battery bank position in the battery system since the use of the same charging methodology with batteries of different battery chemistries will often result in one battery being overcharged while another battery remains undercharged.

The use of multiple chargers is wasteful in that often one battery is severely discharged while another may be nearly fully charged such that only 1/n of the available power is available for charging an individual bank.

The single common primary scheme described above often requires that each of the secondary side rectifiers be rated for the full power of the charger and usually such systems fail to provide for individual control of current and voltage to any given battery or battery bank.

Systems employing the single main charger and secondary side post regulator circuits require a plurality of secondary side control circuits. Often these systems are configured such that there is a full power high priority bank with a plurality of reduced power outputs.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention there is provided a method for charging batteries in a system of batteries. The method involves charging the

batteries according to a dynamic charging sequence in which batteries are added into the charging sequence in order of increasing state of charge as batteries already in the charging sequence are charged to exceed the state of charge of a battery having the next higher state of charge relative to the state of charge of the batteries already in the charging sequence.

In accordance with another aspect of the invention there is provided a method for charging batteries involving producing a set of state of charge signals indicative of the states of charge of each battery in the system, successively identifying, from the state of charge signals, a most discharged battery in the system and applying a charging current to the most discharged battery for at least part of a first period of time less than a period of time required to fully charge the most discharged battery before identifying a succeeding most discharged battery in said system.

In accordance with another aspect of the invention, there is provided an apparatus for charging batteries in a system of batteries. The apparatus includes a state of charge signal generator operable to produce state of charge signals indicative of the states of charge of each battery in the system, a power supply operable to produce a charging current, a current distributor operable to selectively connect each battery in the system to the power supply in response to a control signal and a controller. The controller is configured to communicate with the state of charge signal generator to produce a set of the state of charge signals indicative of the states of charge of each battery in the system and successively identify, from the set of state of charge signals, a most discharged battery in the system. The controller is also configured to produce the control signal so as to cause the current distributor to selectively connect the most discharged battery to the power supply such that the most discharged battery receives the charging current from the power supply for at least part of a first period of time less than a period of time required to fully charge the most discharged battery, before identifying a succeeding most discharged battery in said system.

In accordance with another aspect of the invention, there is provided an apparatus for charging batteries in a system of batteries. The apparatus includes provisions for producing a set of state of charge signals indicative of the states of charge of each battery in the system, provisions for successively identifying, from the state of charge signals, a most discharged battery in the system and provisions for applying a charging current to the most discharged battery for at least part of a first period of time less than a period of time required to fully charge the most discharged battery before identifying a succeeding most discharged battery in said system.

In accordance with another aspect of the invention there is provided a method for use in a charger for charging batteries in a system of batteries. The charger includes a state of charge signal generator operable to produce state of charge signals indicative of the states of charge of each battery in the system, a controllable power supply operable to produce a charging current, a current distributor operable to selectively connect each battery in the system to the power supply in response to a control signal, and a controller operable to communicate with the state of charge signal generator, the power supply and the current distributor. The method is a method of operating the controller and involves causing the controller to communicate with the state of charge signal generator to produce a set of the state of charge signals indicative of the states of charge of each battery in the system, causing the controller to successively identify, from the state of charge signals, a most discharged battery in the system and causing the controller to produce the control signal to cause the current distributor to selectively connect the most discharged battery to the power supply such that the most discharged battery receives charging current from the power supply for at least part of a period of time less than a period of time required to fully charge the most discharged battery, before causing the controller to identify a succeeding most discharged battery in said system.

In accordance with another aspect of the invention there is provided a computer readable medium comprising codes for directing a controller in a charger for charging batteries in a system of batteries. The charger includes a state of charge signal generator operable to produce state of charge signals indicative of the states of charge of each battery in the system, a controllable power supply operable to produce a charging current and a current distributor operable to selectively connect each battery in the system to the power supply in response to a control signal. The controller is operable to communicate with the state of charge signal generator, the power supply and the current distributor. The computer readable medium includes codes readable by the controller for directing the controller to communicate with the state of charge signal generator to produce a set of the state of charge signals indicative of the states of charge of each battery in the system, and to successively identify, from the state of charge signals, a most discharged battery in the system. The codes also direct the controller to produce a control signal to cause the current distributor to selectively connect the most discharged battery to the power supply such that the most discharged battery receives charging current from the power supply for at least part of a period of time less than a period of time required to fully charge the most discharged battery, before causing the controller to identify a succeeding most discharged battery in said system.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

Figure **1** is a block diagram of an apparatus according to a first embodiment of the invention;

Figure **2** is a block diagram of an apparatus according to a second embodiment of the invention;

Figure **3** is a schematic representation of a first embodiment of a current distributor shown in Figures **1** and **2**;

Figure **4** is a schematic representation of a second embodiment of a current distributor shown in Figures **1** and **2**;

Figure **5** is a third embodiment of a current distributor shown in Figures **1** and **2**;

Figure **6** is a schematic representation of a branch circuit of the current distributor shown in Figure **5**;

Figure **7** is a fourth embodiment of a current distributor shown in Figures **1** and **2**;

Figure **8** is a fifth embodiment of a current distributor shown in Figures **1** and **2**;

Figure **9** is a flowchart of a method according to a first embodiment of the invention;

Figure **10** is a flowchart of codes executed by a processor in Figure **2** to carry out blocks **152** and **154** of the method shown in Figure **9**;

Figure **11** is a flowchart of a port charging routine executed by the processor circuit shown in Figure **2** to carry out block **156** of the method shown in Figure **9**;

Figure **12** is a flowchart of a main routine executed by the processor of Figure **2**, including an active port detection routine for detecting which of a plurality of ports of the current distributor shown in Figure **2** has a battery or battery bank connected thereto; and

Figure **13** is a flowchart of the active port detection routine shown in Figure **12**.

DETAILED DESCRIPTION

Referring to Figure **1**, a system of batteries is shown generally at **11**. The system may include any number "n" of batteries. For explanatory purposes the system includes three batteries **12**, **14**, and **16,** which may include separate batteries or separate banks of batteries. The batteries **12**, **14**, and **16** may be of the same type such as lead-acid type or may be of different types, such as lead acid and nickel-cadmium, nickel metal hydride or any other types, for example.

An apparatus for charging the batteries **12**, **14**, and **16** in the system, according to a first embodiment of the invention is shown generally at **10**. Generally, the apparatus **10** includes a state of charge signal generator **18** operable to produce state of charge signals indicative of the states of charge of each battery **12**, **14**, and **16** in the system **11**. The apparatus **10** further includes a power supply **20** operable to produce a charging current and further includes a current distributor **22**. Desirably the power supply may be controllable in that its voltage and current may be controlled. The power supply may be of the constant voltage, or constant current types.

The power supply **20** has positive and negative poles **21** and **23**. The positive pole **21** is connected to the current distributor **22** by a power supply bus **24** and the current distributor is operable to selectively connect each battery **12,** **14** and **16** in the battery system **11** to the power supply bus **24**, in response to a control signal. The apparatus **10** further includes a controller **26** configured

to effect a charging process in which it communicates with the state of charge signal generator **18** to produce sets of state of charge signals indicative of the states of charge of each battery **12, 14** and **16** in the battery system **11**. The controller itself may be part of the state of charge signal generator **18**. As part of this charging process, the controller **26** is also configured to successively identify from a given set of state of charge signals a most discharged battery in the system of batteries **11** and to produce the control signal for reception at an input **25** of the charge current distributor **22**. The control signal is produced to cause the charge current distributor **22** to selectively connect the most discharged battery in the system to the power supply **20** by connecting at least one pole of the power supply to the most discharged battery such that the most discharged battery receives the charging current from the power supply bus **24** for at least part of a period of time less than a period of time required to fully charge the most discharged battery, before communicating again with the state of charge signal generator **18** to identify a succeeding most discharged battery in said system.

The state of charge signal generator **18** may include any device that produces a signal indicative of the state of charge of a battery **12, 14 and 16** in the battery system **11**. Referring to Figure **2**, a second embodiment of the invention is shown at **27** in which the state of charge signal generator **18** includes a voltage sensor **28** in communication with the power supply bus **24** to measure voltage on the power supply bus **24** when the current distributor **22** connects the power supply bus **24** to the most discharged battery. Alternatively separate voltage sensors (not shown) may be used on each charging port.

The apparatus **10** may include a current signal sensor **34** operable to sense current on the power supply bus **24** and operable to produce a current signal for reception at an input **36** of the controller **26**.

Referring to Figure **3**, the charge current distributor **22** may include a switching circuit **29** implemented as a single pole multi-throw switch having a common contact **40** connected to the power supply bus **24** and having a plurality of port contacts, three of which are shown at **42**, **44**, and **46**, defining three battery charging ports operable to be selectively connected to the positive terminals of respective batteries **12, 14 and 16** or battery banks of the battery system **11**. The charge current distributor **22** may have contacts defining any number of battery charging ports. The single pole multi-throw switch also has a wiper **50** operable to selectively connect the common contact **40** to any of the port terminals **42**, **44**, and **46**. The switching circuit may be implemented by any type of actuated contact device such as a rotary switch, for example, driven by a stepper motor (not shown) controlled by the control signal produced by the controller **26** shown in Figure **2**.

Alternatively, referring to Figure **4**, the charge current distributor **22** may include a switching circuit implemented by a plurality of single pole, single throw switches, three of which are shown at **52**, **54**, and **56**, each having a first terminal **60**, **62**, and **64**, respectively, connected to each other and to the power supply bus **24**. Each switch **52**, **54**, and **56** also has a respective second terminal **68**, **70**, and **72** acting as a port terminal to which a respective positive terminal of a battery or battery bank may be connected. Each switch **52**, **54**, and **56** also has a respective wiper **76**, **78**, and **80** selectively operable to connect its associated respective common terminal **60**, **62**, and **64** to a respective port terminal **68**, **70**, and **72**. The embodiment shown in Figure **4** may be realized by employing a plurality of single pole, single throw relays (not shown), the coils of the relays being selectively activated in response to the control signal produced by the controller **26**. Alternatively, the embodiment shown in Figure **4** can employ the switching circuit described below relative to Figure **5** or other converted semiconductor switches. Herein, the term "control signal" refers to any signal or collection of signals activated or modulated in any manner determined by the specific implementation of the current distributor **22** under consideration to permit the controller **26** that produces the

control signal to selectively connect ports of the current distributor **22** to which batteries or battery banks are connected to the power supply bus **24**.

Referring to Figure **5**, in a further alternative implementation, the current distributor **22** may include a switching circuit implemented by a plurality of semiconductor branch circuits shown generally at **90**, **92** and **94**. Each branch circuit **90**, **92** and **94** has a respective common terminal **96**, **98**, and **100** connected to the power supply bus **24** and each branch circuit has a respective port terminal **102**, **104** and **106** to which the positive terminals of respective batteries or battery banks of the battery system **11** may be connected.

Referring to Figure **6**, a representative branch circuit of the type shown in Figure **5** is shown generally at **110** and includes first and second metallic oxide semi-conductor field effect transistors (MOSFETS) **112** and **114** connected in an anti-series totem pole arrangement between the power supply bus **24** and a port terminal **118**. This arrangement permits blocking of reverse current through the MOSFET body diode which inherently provides for reverse battery polarity protection. The MOSFETS **112** and **114** are driven by gate drive signals on respective conductors **124** and **125.** The gate drive signals are provided by a gate drive unit **128** which produces the gate drive signals in response to a control signal received at a control signal input **130** from the controller **26**. The gate drive signals are referenced to a reference point between the MOSFETS **112** and **114**, which is connected to the gate drive unit **128** by a conductor **126**. When the control signal is active, the gate drive unit **128** produces gate drive signals that turn on both MOSFETS **112** and **114** to provide a very low resistance conducting path between the power supply bus **24** and the port **118**. Similarly, when the control signal received at the gate drive unit **128** is inactive, both MOSFETS **112** and **114** are turned off, thus preventing any flow of current from the power supply bus **24** to the corresponding port **118**. Alternative implementations of the current distributor can be provided by replacing MOSFET **112** with a diode, or alternative

semiconductor devices such as Bipolar Junction Transistors (BJTs) could be used. If reverse polarity protection is not desired, and only small differences in voltages between banks are expected (less than a diode voltage drop), then MOSFET **112** may be omitted and MOSFET **114** may be connected between the power supply bus **24** to port **118** could be performed. Alternatively a bipolar junction transistor could be substituted for MOSFET **112** and directly connected to the port with (or without) a series diode. These alternative implementations may not provide complete bi-directional isolation of ports (**118, 102, 104,** or **106**) from the power supply bus **24**, over a full range of system voltage conditions, however.

Referring to Figure **7**, in another implementation of the charge current distributor **22**, the charge current distributor comprises first and second switching circuits **140** and **142**, each of which may include any of the switching circuits shown in Figures **3-5**. Each switching circuit **140** and **142** is used to selectively connect respective poles of a battery or battery bank to the positive pole of the power supply **20** and to a common reference conductor **144** to which a negative pole of the power supply **20** is connected. This embodiment employing two switching circuits may be used where each battery or battery bank is electrically isolated.

Referring to Figure **8**, the embodiment shown in Figure **7** may alternatively be used where the batteries or battery banks are connected in series. In this embodiment, care must be taken to ensure that the negative pole of the power supply **20** is not connected to a negative pole **145** of the battery system **11** to ensure that when the second switching circuit **142** is connected to any battery other than the battery on port **1,** in the embodiment shown, a short circuit does not occur.

In general the switching circuits shown in Figures **3-5**, **7**, or **8** may be used to connect the most discharged battery to at least one pole of the power supply **20**.

Referring to Figure **9**, a method carried out by the apparatus **10** shown in Figure **1** and the apparatus **27** shown in Figure **2** is shown generally at **150** and involves a first action **152** wherein the apparatus produces a set of state of charge signals representing the state of charge of each battery or battery bank in the battery system. The method further includes action **154** wherein the apparatus identifies the most discharged battery from the set of state of charge signals. The method further includes action **156** in which a charging current is applied to the most discharged battery for a period of time less than a period of time required to fully charge the most discharged battery. On completion of action **156**, the apparatus repeats the actions shown in Figure **9** and produces another set of state of charge signals (block **152**), identifies from that set the most discharged battery (block **154**) and applies charging current to the most discharged battery for a period of time less than a period of time required to fully charge the most discharged battery (block **156**). Alternatively state of charge signals may continually be produced and the most discharged battery identified therefrom after a charging current has been applied to the previously identified most discharged battery. Thus, in general the method involves producing sets of state of charge signals indicative of the states of charge of each battery in the system, successively identifying from the state of charge signals the most discharged battery in the system and applying a charging current to the most discharged battery for a first period of time less than a period of time required to fully charge the most discharged battery, before identifying a succeeding most discharged battery in said system.

The effect of this method is to cause the most discharged battery or battery bank in the system to be charged first or at least up until its state of charge is in a range of or exceeds that of the next most discharged battery or battery bank in the system. Then, the effect of the method is to charge the two batteries or battery banks exhibiting this next higher state of charge, somewhat alternately, until the state of charge of at least one of the two

batteries being alternately charged exceeds the state of charge of the battery or battery bank in the system exhibiting the next higher state of charge. Then, the three batteries or battery banks exhibiting generally this next most discharged state of charge are alternately charged until the state of charge of at least one of these three batteries or battery banks exceeds the state of charge of the next most discharged battery or battery bank in the system, and so on. In this manner, a charging sequence is established whereby the most discharged battery or battery bank receives charging current first, and batteries or battery banks are added to the sequence in order of increasing state of charge, until all batteries or battery banks in the system are charged to approximately the same level. More generally, a dynamic charging sequence is established in which batteries or battery banks are added to the charging sequence in order of increasing state of charge as batteries or battery banks already in the charging sequence are charged to exceed the state of charge of a battery or battery bank having the next higher state of charge relative to the state of charge of the batteries or battery banks already in the charging sequence.

The charging sequence produced by the apparatus and methods described herein is particularly suited to use with flooded lead acid-type batteries, for example, as such batteries should not remain at a low state of charge for a long period of time and are prevented from doing so since the battery or battery bank with the lowest state of charge is considered the most important battery to charge first and this minimizes the time during which that battery is deprived of its full state of charge, before the next most discharged battery is added to the charging sequence.

Referring back to Figure **2**, to implement the methods described herein in the embodiment shown, the controller **26** includes a processor circuit **160** in communication with an (input/output) I/O port **162** and in communication with random access memory (RAM) **164** and program memory **166**. The I/O port **162** is operable to receive signals from the voltage sensor **28** and from the

current signal sensor **34**. In this embodiment, the I/O port **162** also includes outputs **168** and **170** for supplying a reference current signal and a reference voltage signal, respectively, to the power supply **20**. The reference current signal determines the maximum current output of the power supply **20** and the reference voltage signal specifies a regulated voltage of the power supply when the power supply is operating at less than its maximum current value.

In this embodiment, the program memory **166** may include memory on an integrated circuit containing the processor circuit **160** or it may include a separate chip, such as an electrically erasable programmable read only memory, for example. The program memory **166** is programmed with codes for directing the processor circuit **160** to control the charge current distributor **22** in response to the states of charge of the batteries, as represented at least by the signal from the voltage sensor **28**, to carry out the method described above with reference to Figure **9**.

Referring to Figures **2** and **10**, in this embodiment, the program memory **166** is loaded with a first block of codes represented by block **180** that direct the processor circuit **160** to start a charging process by communicating with the I/O port **162** to produce current and voltage reference signals on outputs **168** and **170** to cause the power supply **20** to reduce its output current and voltage to zero and to cause it to effectively be isolated from the power supply bus **30**. In this embodiment, the processor circuit **160** sets the current and voltage reference signals to zero and in response the power supply **20** is de-energized.

In addition, block **180** also includes codes that direct the processor circuit **160** to cause control signals to be produced for receipt by the charge current distributor **22** to cause the charge current distributor to successively connect each port to the power supply bus **24**. While a given port is connected to the power supply bus **24**, the block **180** directs the processor circuit **160** to read the voltage signal produced by the voltage sensor **28** to measure the voltage

of the battery or battery bank connected to the currently connected port. In this embodiment, the voltage signal is considered to be a signal representing the state of charge of the battery or battery bank connected to the port. A digital representation of the voltage signal is saved in the RAM **164** and is associated with a corresponding port identifier. Then the next port is connected and a corresponding voltage measurement is taken and stored as described above. This process of connecting and measuring voltage is repeated for each port until a set of voltage measurements is produced. This set of voltage measurements acts as a set of signals representing the states of charge of the batteries or battery banks in the battery system **11**.

Alternatively, separate voltage sensors (not shown) may be used on each part to continuously or independently produce a set of voltage measurements that can be used by the following block **182** in the process.

After a set of signals representing the states of charge of the batteries or battery banks in the system has been acquired and stored in the RAM **164**, block **182** directs the processor circuit **160** to sort the voltage values in ascending order to determine the voltage measurement having the lowest value.

Alternatively, in the case where voltage measurements are taken at the beginning of each charging cycle as each voltage measurement is taken, it may be compared to a currently stored voltage measurement and the currently stored voltage measurement may be replaced with the lowest voltage measurement of the comparison. In this manner, the lowest voltage value of each successive measurement is determined as the voltage at each successive port is measured. Nevertheless, as will be seen below, it may be desirable to store a complete set of voltage measurements for the batteries or battery banks for future use.

In the embodiments described herein, the voltage measurement having the lowest value is considered to be associated with the battery or battery bank that is in the lowest state of charge, i.e., the most discharged battery or battery bank.

The port associated with voltage measurement having the lowest value is therefore identified as the port to charge by associating a charge flag in the RAM **164**, for example, with that port.

Referring to Figure **11**, after identifying the port to charge, a port charging routine as shown generally at **190** is executed by the processor circuit **160**. The port charging routine **190** includes a first block of codes **192** that directs the processor circuit **160** to cause the I/O port **162** to produce a control signal that causes the current distributor **22** to connect the identified port associated with the most discharged battery to the power supply bus **24** to begin charging the battery or battery bank connected to the identified port. Then, block **194** directs the processor circuit **160** to implement and start a port pulse timer according to the port type. Where the port is to be used to charge a flooded lead acid battery, the port type is “flooded lead-acid” and the port pulse timer may be set to provide a first time period that may be fixed or programmable. RAM **164** may store user input, such as port type, to determine the first time period.

The first time period is selected so that the battery being charged is able to receive sufficient current such that it is able to increase or maintain its current state of charge even with a load connected thereto. The ability of the battery to increase or maintain its state of charge depends upon the charge acceptance or coulombic charge efficiency of the battery, which depends upon the chemical type of the battery or battery chemistry and state of charge (SOC). In a flooded lead-acid type of battery, the charge acceptance of the battery is dependent upon the current state of charge of the battery, i.e., whether the state of charge will permit the battery to accept bulk charging,

absorption charging or float charging current. In addition within each of these phases the ability of the battery to accept charge depends upon how long a charging current has been supplied. For example, the charge acceptance of a flooded lead-acid type battery in any charging phase is greater upon initial application of a charging current than some time after the charging current has been applied. In other words, the charge acceptance of the battery decreases from an initial value, over time, while charging current is applied to the battery.

To allow for different levels of charge acceptance in the different phases of battery charging and to allow for user-applied DC loads which may be or may become present while charging, in the embodiment described, the first time period is selected such that over a plurality of first time periods the battery receives a net charge gain or at least is able to maintain its present charge state. For a flooded lead acid battery, for example a net charge gain is desired during the bulk and absorption phases of charging and maintaining a current state of charge is desirable during the float phase of charging. If a single first time period is to be used in each of these phases, the first time period must be selected such that when a maximum expected load is applied to the battery during charging, a net state of charge gain is seen at the battery during the bulk and absorption phases and maintenance of the current state of charge of the battery is seen during the float phase. Alternatively, different first time periods may be used in corresponding phases or groups of phases, for example. The controller may use current and voltage measurements, for example, to determine the current charging phase of the battery and select an appropriate first time period accordingly.

For a flooded lead-acid battery, a suitable first time period may be determined empirically by measuring the average long-term steady state of charge of the battery after applying the charging methods described herein with different first time periods and different loads connected to the battery and selecting as a desirable first time period the one that permits a net state of charge gain

during the bulk and absorption phases of charging and that maintains a state of charge of the battery during the float phase. Results have shown that a first time period of between about **1** and about **30** seconds and more particularly about **20** seconds is suitable for a **200** Amp-Hour Deep Cycle flooded lead-acid battery at about **20** degrees Celsius bearing a user-connected load of approximately **10** Amps.

Since charge acceptance drops with time, relatively short first time periods are desirable, however, it may be desirable to ensure that resulting current and/or voltage fluctuations appearing at the battery do not interfere with loads that may be connected to the battery. Time periods under about **1** second in a two battery system may cause a perceptible flicker in lighting circuits connected to one or the other of the batteries. Time periods on the order of milliseconds can cause transients to appear at the battery and such transients may create interference with electronic equipment connected to the battery being charged such as a perceptible buzzing sound in poorly filtered audio systems. Time periods on the order of microseconds or even shorter time periods can cause radio frequency interference. Thus it is desirable to ensure the first time period is long enough to avoid electrical interference resulting in effects that are perceptible by humans in loads connected to the battery or battery bank being charged and to avoid un acceptable radio frequency disturbances.

Still referring to Figure **11**, after block **194**, block **196** directs the processor circuit **160** to determine whether the port pulse timer has timed out or is still activated. If it has timed out, a cycle of the charging process defined between blocks **180** and **196** is considered to be completed and the processor circuit **160** is directed back to block **180** shown in Figure **10** where it begins another cycle of the charging process, as described above.

During the time period in which a battery or battery bank is being charged, the controller **26** may monitor the voltage and current applied to the battery and adjust the Vref and Iref values accordingly to maximize charging efficiency

depending on the ability of the battery or battery bank to accept charge as indicated by the monitored voltage and current. Selectable charging profiles may be entered by the user and stored in RAM **164**, or non-volatile memory (not shown), accessible by the processor circuit **160,** or predefined profiles may be stored in any memory accessible by the processor circuit **160.** The controller **26** may provide optimum charging efficiency by controlling the power supply **20** to produce a charging current according to the charging profile associated with the most discharged battery connected to the identified port.

Enhancements

The charging process may be enhanced by including within the port charging routine **190** a test relating to the current supplied to the battery or battery bank being charged.

For example, the processor circuit **160** may be programmed with blocks of codes **198** and **200** for directing it to implement a current criteria test to determine whether or not the current supplied to the battery or battery bank being charged rapidly falls off within a period of time within the first period of time. Such a rapid falling off of charging current would be typical of a lead-acid battery in the absorption phase, for example. Typically in this phase, the current supplied to the battery or battery bank will be very high initially but will drop off exponentially over a very short time. Typically this very short time is within the first period, i.e., much less than the approximately twenty seconds described above and may be on the order of about one to five seconds, for example. It is desirable, however, to minimize the effect of transient currents on loads connected to the battery, to ensure that the battery is exposed to a charge current pulse of a minimum time duration such as one second, for example. Thus, block **194** may also include codes that implement a minimum period timer and block **198** may direct the processor circuit **160** to determine whether or not a minimum time period has passed since the first period timer was set. This minimum period may be subject to the same constraints as the

minimum time for the first period, for example, in a marine application, where it is desirable to avoid unwanted interference in loads connected to the battery being charged. In a marine application with a flooded lead acid battery, the minimum time period may be between about **1** second and about **5** seconds, for example.

If at block **198** the minimum time period has not elapsed, no action is taken and the processor circuit **160** is directed back to block **196**. If the minimum time period has passed, the processor circuit **160** is directed to the second set of codes **200** which causes it to determine whether or not, after the above described minimum time period and before the expiry of the first time period, the current supplied to the battery or battery bank currently being charged is less than a threshold level. If it is not, then no action is taken and the processor circuit **160** is directed back to block **196**. If the current supplied to the battery or battery bank is less than the threshold level, the processor circuit **160** is directed back to block **180** shown in Figure **10** to begin another charging cycle without completing the first time period. In general it will be appreciated that effectively, the most discharged battery is disconnected from the power supply during the first period of time when the charge current meets a first criterion being that the charge current is less than a threshold value after a minimum period of time, within the first period of time, in this embodiment.

Optionally, to reduce time taken to check the states of charge of all of the batteries or battery banks when the state of charge of the battery exhibiting the lowest state of charge is significantly different from the state of charge of the battery or battery bank having the next higher state of charge, block **201** may be included in the "yes" path from block **196** to direct the processor circuit **160** to monitor the state of charge of the battery or battery bank being charged to determine whether it is equal to or exceeds the state of charge of the battery or battery bank exhibiting the next higher state of charge. This may be achieved by monitoring the voltage at the power supply bus **24** which

is indicative of the voltage at the battery or battery bank being charged, and comparing it to the voltage measurements in the set of voltage measurements taken during the last execution of block **180**. When the present voltage measured at the power supply bus **24** (representing the state of charge of the battery being charged) is equal to or greater than the next higher voltage measurement in the last-acquired set of voltage measurements, block **201** causes the processor circuit **160** to continue charging the battery or battery bank currently being charged. When the voltage measured at the power supply bus **24** is equal to or greater than the next higher voltage measurement in the last-acquired set of voltage measurements the processor circuit **160** is directed to end the port charging routine and return to block **180** in Figure **10** to begin another charging cycle. In this manner, the battery or battery bank exhibiting the lowest state of charge is continuously charged until its state of charge exceeds the next higher state of charge in the battery system whereupon the battery associated with the next higher state of charge is then also subjected to charging.

Active Port Detection

Referring to Figure **2**, it will be appreciated that the charge current distributor **22** has a plurality of ports. However, not every port may have a battery connected to it. The routines shown in Figures **12** and **13** may be included in the program memory **166** along with those shown in Figures **10** and **11** to cause the processor circuit **160** to scan the ports so as to determine which ports are "active" ports and which ports are "inactive" ports and to ensure that, during a charging cycle, state of charge signals are only sought from active ports. Active ports are ports which have batteries connected thereto and inactive ports are ports to which no battery is connected, although such ports may have loads connected thereto.

Referring to Figures **2** and **12**, in this embodiment and to provide for detection of active and inactive ports, the program memory **166** includes codes that implement a main routine **210** as shown in Figure **12**. The main routine

includes an active port detection block **212;** a block **214** similar to block **180** shown in Figure **10**, which directs the processor circuit **160** to determine the state of charge for each active port; a block **216** similar to block **182,** which directs the processor circuit **160** to identify an active port to charge; and includes block **218** which is the same as the port charging routine **190** shown in Figure **11,** with or without the optional current test blocks **198** and **200**. Finally, the main routine **210** includes block **220** which directs the processor circuit **160** to determine whether or not it is time to detect active ports. If it is not time to detect active ports, the processor circuit **160** is directed to block **214** to resume processing as shown, or if it is time to detect active ports, the processor circuit **160** is directed to block **212** where it again performs an active port detection function.

At block **220**, where the processor circuit **160** determines whether or not it is time to detect active ports, a separate timer (not shown) may be maintained by the processor circuit **160**, the separate timer marking time periods of about ten minutes, for example, so that about every ten minutes the processor circuit **160** interrupts the charging process and is directed to the active port detection block as shown at **212** in the main routine **210**. Otherwise, the processor circuit **160** loops through the blocks shown at **214**, **216** and **218** to carry out the charging method shown in Figure **9**.

Referring to Figure **13**, an exemplary active port detection routine as implemented by the active port detection block **212** shown in Figure **12** is shown generally at **230**. The active port detection routine **230** begins with a first block **232,** which directs the processor circuit **160** to set a port counter variable p=**1** to identify the first port as the selected port. Then, block **234** directs the processor circuit **160** to recall from RAM **164**, for example, or from the program memory **166,** a test voltage and a test current for the type of battery connected to the first port. The test voltage and test current may be set by the user and stored in a lookup table, for example, in the RAM **164**. Alternatively, these values may be stored in a lookup table, for example, in the

program memory **166** as fixed values. It may be desirable to set the test voltage to a value corresponding to the absorption voltage of the battery and to set the test current value to the maximum charging current of the battery.

After recalling the absorption voltage and maximum current for the selected port, block **236** directs the processor circuit **160** to produce a signal for receipt by the power supply **20** causing it to set the reference voltage and reference current to the test voltage and test current values, respectively. This allows limits to be set on the power supply **20** to ensure that excessive voltages and excessive currents are not presented to a battery connected to a port connected to the power supply bus **24**, thereby activating port p so as to permit a current to be drawn from port p.Next, block **238** directs the processor circuit **160** to produce control signals to cause the charge current distributor **22** to connect the port identified by the port variable p to the power supply bus **24**. Then, block **240** directs the processor circuit **160** to wait for a period of time, for example **100** milliseconds, and then block **242** directs the processor circuit **160** to read the current supplied to the selected port, as indicated by the current sensor **34** and to determine whether or not the current on the power supply bus is greater than a current value. Effectively, blocks **240** and **242** cause the processor circuit **160** to determine whether or not, after a period of time, the current on the power supply bus **24** is greater than a threshold current value. If so, block **244** directs the processor circuit **160** to identify the currently selected port as an active port. If the test at block **242** is negative, block **246** directs the processor circuit **160** to identify the currently selected port as inactive. Identifying a port as active or inactive may simply involve keeping a list of port numbers and associating with the port numbers in the RAM **164** a flag having the value of one or zero to indicate active and inactive, respectively.

After identifying the currently selected port as being either active or inactive, block **246** directs the processor circuit **160** to determine whether or not all of the ports available at the current distributor **22** have been checked and, if not,

block **248** directs the processor circuit **160** to set the port variable to the next port in the sequence and the processor circuit **160** resumes processing at block **234** as described above. If all of the ports have been checked, the active port detection routine is concluded and the processor is directed to block **214** of Figure **12** where it resumes execution of cycles of the charging process.

It should be noted that the active port detection routine includes the time delay provided by block **240** to allow the current supplied by the power supply to settle to a non-transient value. The time required to reach this value and the value itself depend upon the type and magnitude of the load across the battery port being tested. For example, a capacitive load may be connected instead of a battery or battery bank to a part of the current distributor. This may occur where a battery to be charged is removed from a circuit connected to a charging port. This may be a typical occurrence in a marine application for example. It will be appreciated that this embodiment block **240** provides a way of distinguishing between loads and batteries connected to the charging ports. It will be appreciated that more elaborate algorithms for achieving this goal could be employed.

The apparatus and method described herein inherently blocks current flow out of batteries which are not being charged and causes current not to be supplied to batteries or battery banks in a higher state of charge until the states of charge of other batteries in the system are brought up to such levels. The most discharged, or least charged battery is charged first then the next most discharged battery is charged by multiplexing current between the previously least charged battery and the previously next most discharged battery and more and more batteries are charged in this manner until all batteries are fully charged. Thus charging current is focussed on the least charged batteries and the full output of the charger can be focussed on the least charged batteries. This also allows for full control over charging and allows individual charging profiles to be used to charge each individual

battery, permitting batteries with different chemistries to be charged by the same charger. In addition, the apparatus and methods described herein permit batteries or battery banks to be added or subtracted from the system, without powering down the charger.

In addition, the charging methods and apparatus described herein are particularly well-suited for use in systems where different types of DC loads may be connected or disconnected across one or more batteries of the system. Charging is still permitted to occur in the presence of user-applied DC loads across a battery or battery bank to be charged.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.